

Optimization of Lateral Vehicle Dynamics by Targeted Dimensioning of the Rim Width

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ABSTRACT

The aim of this investigation is the improvement of the lateral vehicle dynamics by optimizing the rim width. For that purpose, the rim width is considered as a development tool and configured with regard to specified targets. Using a specifically developed method of simulation, the influence of the rim width is analysed within different levels - starting at the component level "tyre" and going up to the level of the whole vehicle. With the help of substantial simulations using a nonlinear two-track model, the dimensioning of the rim width is brought to an optimum. Based on both, tyre and vehicle measurements, the theoretical studies can be proved in practice. As a result, the rim width has a strong influence on the behaviour of the tyre as well as on the overall vehicle performance, which emphasises its importance as a potential development tool within the development of a chassis.

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INTRODUCTION

Distinct lateral vehicle dynamics is a key component of the vehicle's market positioning. In addition to the well-known trade-off between vehicle dynamics and ride quality, especially the aim for high fuel efficiency raises new challenges with respect to vehicle dynamics development [1]. To this extent it is necessary to investigate novel, pareto- or at least near pareto-optimal solutions by means of well-structured, simulation-aided processes, which allow for high accuracy forecasts as well as the consideration of interactions between vehicle dynamics and ride quality. Consideration of rim width for vehicle dynamics target achievement is a possible solution which has not been investigated thoroughly before.

In literature different approaches for targeted designing of vehicle dynamics and comfort can be found. It has to be noted, that this literature survey can only give an overview on the typical approaches, due to the large number of investigations in this field. WIMMER describes the classical designing process, where the different subsystems like chassis or tyre were separately developed through the designing process [2]. A common approach is introduced from KIM ET. AL, who define different targets on full vehicle level, which were transferred to the assembly and component level by using simulation

models of different complexity [3]. This method is also known as "Target Cascading". In general it can be established, that there are various methods on the basis of optimizers, control engineering and different evaluation algorithms by using detailed two-track-models for targeted design of the lateral vehicle dynamics with different objective parameters [e.g. 4, 5, 6]. GOBBI finally proposes an approach with neuronal networks and complex simulation models to optimize the lateral vehicle dynamics and comfort [7].

Therefore, in this paper a vehicle dynamics development method is presented, based on a number of criteria and individually chosen weighting factors, depending on the desired vehicle attribute positioning. This method is subsequently used for individual rim width dimensioning on the front and rear axle, so that the vehicle dynamics performance is increased. To this extent, firstly, the influence of the rim width on relevant tyre characteristics is investigated using test rig methods. Knowledge of rim width influence is subsequently used in the simulation-based development method, which is finally validated using vehicle measurements with the chosen optimal rim width configuration. It is shown that, by appropriate rim width dimensioning, vehicle dynamics attributes of an 18" wheel can be partially achieved using a smaller 17" wheel, leaving an advantage w.r.t. ride quality.

SIMULATION METHOD

The aim of this investigation is a targeted improvement of the lateral vehicle dynamics using the development variable rim width. In the framework of this investigation, therefore a simulation method, which enables a structured solution of a development task with one or more development variables, is developed. Figure 1 shows the simulation method with the inputs and outputs.

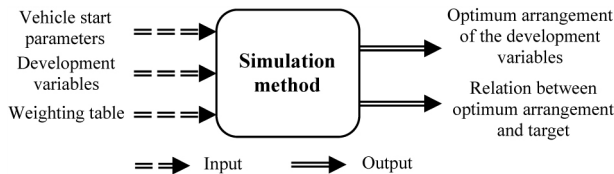


Figure 1. Input and output of the simulation method

The simulation method's input includes vehicle start parameters on full vehicle level, the development variables and a weighting table. The vehicle start parameters represent the current state of a vehicle on full vehicle level (e.g. a predecessor vehicle) and are the base of the further development. The development variables are important levers on both assembly and component level. With the help of these variables it is possible to achieve or overcome a target configuration, which has to be defined in the process. The weighting table is therefore used to take the user's individual preferences of parameters into account.

The simulation method's output is the optimum arrangement of the development variable(s). At the same time the method supplies a relation between the results and the optimum arrangement. For this purpose there is a need to define all development variables and vehicle parameters as vectors.

The construction of the simulation method is based on the typical V-Model of the Systems Engineering Process and is separated into six different steps. These six steps contain the three development levels: full vehicle level, assembly level and component level.

Figure 2 shows the simulation method's complete structure. All following explanations relate to only one development variable (e.g. the rim width). Thus the vector $\vec{x}$ of the development variable has only one row, which leads to a scalar x . The vehicle parameters are, as mentioned before, combined in a vector. To operate the simulation method, the running direction is, according to the V-Model, from the left to the right side. The simulation method's input is defined on the left side, the output on the right side.

At first it is necessary to define the simulation method's input. The vehicle start vector $\vec{Y}_0$ contains the full vehicle parameters of the vehicle, which should be optimized using the simulation method. The basis of all the following investigations is a vehicle, which has a rim-tyre combination of 7.5Jx17 and 225/50 R17 for all four wheels. The vehicle start vector is defined by Formula 1. The vector can be obtained by simulation of the vehicle with the defined vehicle start parameters.

$$\vec{Y}_0 = (Y_{011} \ Y_{012} \ Y_{013} \ Y_{014} \ Y_{015} \ Y_{016} \ Y_{017} \ Y_{018} \ Y_{019})^T \quad (1)$$

The vehicle start vector contains the steering wheel gradient linear $Y_{011} = \left(\frac{d\delta_H}{da_y}\right)_{lin}$ and threshold $Y_{012} = \left(\frac{d\delta_H}{da_y}\right)_{thres}$, the maximum lateral acceleration $Y_{013} = a_{ymax}$, the side slip angle gradient linear $Y_{014} = \left(\frac{d\beta}{da_y}\right)_{lin}$ and threshold $Y_{015} = \left(\frac{d\beta}{da_y}\right)_{thres}$, the natural yaw rate frequency $Y_{016} = f_e$, and the yaw rate gain at 50, 100, 150 km/h $Y_{017,18,19} = \left(\frac{\dot{\psi}}{\delta_H}\right)_{50,100,150}$.

For the purpose of the optimization, in this investigation the development variable x is defined as rim width. With the help of the rim width the lateral vehicle dynamics has to be improved.

Furthermore it is necessary to define the multiplying factors of the weighting vector. Table 1 shows the weighting table in analogy to the Cost-utility analysis mentioned in VDI 2225 [8]. The column called "multiplying factors" leads to the weighting vector $\vec{W}$, which has to be an input to the simulation method.

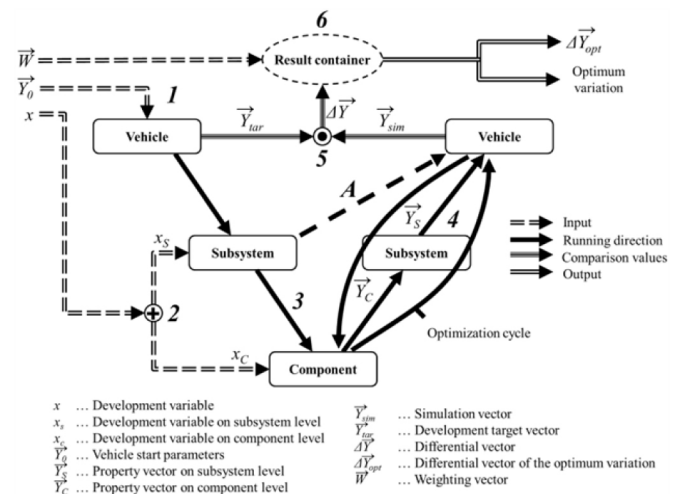


Figure 2. Structure of the simulation method

Table 1. Weighting table with focus on the vehicle handling's optimization

Lateral vehicle dynamics parameter	Weighting	Multiplying factor
Steering wheel gradient linear	+++	-3
Steering wheel gradient threshold	++	+2
Maximum lateral acceleration	+	+1
Side slip angle gradient linear	+	+1
Side slip angle gradient threshold	++	+2
Natural yaw rate frequency at 100 km/h	+++	+3
Yaw rate gain at 50 km/h	+++	+3
Yaw rate gain at 100 km/h	+++	-3
Yaw rate gain at 150 km/h	+++	-3

The weighting and multiplying factors are individually chosen for the purpose of improving the handling of the start vehicle. The positive algebraic sign of the multiplying factor indicates a vehicle parameter, which is better at high values and vice versa.

The next step after defining the simulation method's input is to operate the single steps. According to the procedure of step 1 in Figure 2, it is necessary to define the development target. For the purpose of this research it is the aim to achieve or overcome the lateral vehicle dynamics of the next higher available rim-tyre combination (8.5Jx18 and 245/50 R18) by rearranging the rim width of the 17" tyres. The result of the optimization is a vehicle with similar or even better lateral vehicle dynamics - with the advantages of better comfort (lower vertical stiffness), lower unsprung masses and lower moments of inertia.

The vehicle target vector $\vec{Y}_{tar}$ is similar defined by Formula 1. In this vector all vehicle settings of the target vehicle can be found. This vector is the result of the target vehicle's simulation.

Besides the definition of interactions of the development variable on component or subsystem level (run direction A in Figure 2) in step 2, it is necessary to define a variation space of this variable. To define the variation space of the rim width, the ETRTO is taken into account [9]. The ETRTO recommends a rim width range from 6" to 8" for a tyre dimension of 225/50 R17 (used in this investigation). By taking the measuring expenditure and the ease of assembly into consideration, a rim width range of 6.5" to 8.5" is chosen. The exceed of the maximum rim width by 0.5" can be, according to the ETRTO, agreed in cooperation with a tyre manufacturer via an individual tyre approval process.

In the next step it is necessary to procedure the steps 3, 4, 5 and 6.

INFLUENCE OF THE RIM WIDTH ON LATERAL TYRE CHARACTERISTICS (STEP 3)

To optimize the lateral vehicle dynamics by using the effect of the rim width it is necessary, in analogy to step 3 of the simulation method, to investigate the influence of the development variable on the component level "tyre". With this information conclusions for the vehicle behaviour can be drawn and target configurations to dimension the rim width can be developed. The following section describes the investigation of the rim width's influence on tyre properties.

Tyre Contact Patch

The only connection between vehicle and road surface is the tyre contact patch. Therefore the tyre contact patch has a significant influence on the tyre's characteristic dynamic values. The size of this area is mainly influenced by load and the tyre's internal pressure. To investigate the influence of the rim width on the tyre contact patch three so called "footprints" were created with a wheel load of 5000 N and an internal pressure of 2.4 bar. Figure 3 shows the three footprints with rim widths of 8", 9" and 9.5".

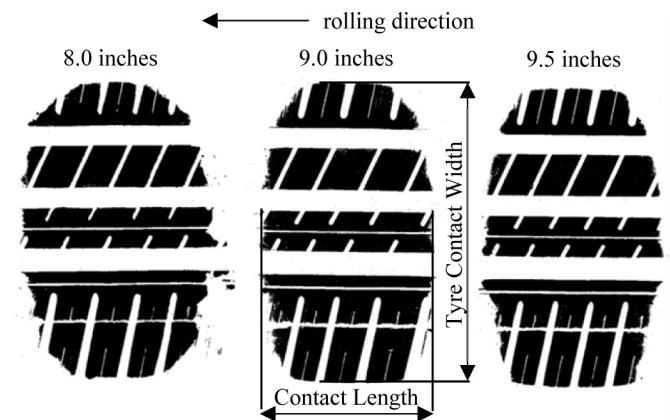


Figure 3. Influence of the rim width on the tyre contact patch

By increasing the rim width the tyre contact width is also slightly increasing (less than 2 %). This behaviour can be described by the additional area of the tyre shoulders due to the expanding of the tyre sidewalls. Figure 3 also shows the transformation of the tyre contact length. Firstly the tyre contact length is reduced from 8" to 9", about 10 %. This behaviour can be explained by the increasing vertical stiffness due to the enlargement of the rim width. An increased rim width with the same wheel load of 5000 N leads to a decreased compression of the tyre (measured about 9 %) and therefore to a smaller tyre contact patch. Further increasing of the rim width from 9" to 9.5" leads to a saturation of the tyre properties and thus to a saturation of the vertical stiffness. Accordingly the tyre compression is almost identical and the contact length is changed insignificant. These two effects change the tyre contact patch from 3 to 4 % over all rim widths. The shape of the tyre contact patch adjusts to a square form with an increasing rim width through the additional areas of the tyre shoulders.

Lateral and Cornering Stiffness

Figure 4 shows the influence of the rim width on the lateral stiffness of two different tyres and different wheel loads. In addition, inserted arrows indicate the effective direction by increasing the rim width.

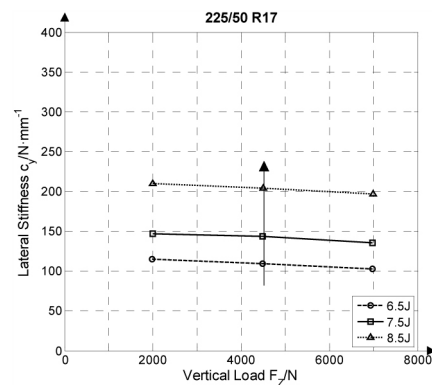


Figure 4. Influence of the rim width on lateral stiffness for two different tyres

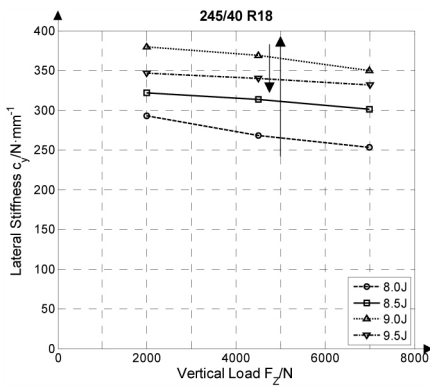


Figure 4. (cont.) Influence of the rim width on lateral stiffness for two different tyres

As seen in Figure 4, an increase of the rim width leads to an increase of the lateral stiffness up to 43 % over the whole wheel load range for tyres of the dimension 17" resp. 18". The explanation for this behaviour can be found by considering the wider mounting of the tyre, which leads to a more trapezoid tyre cross section. This effect leads to a better support of side forces, which causes an increase of the lateral stiffness.

With further increase of the rim width tyres with a dimension of 18" show a reduction of the lateral stiffness up to 8 %. To explain this behaviour Figure 5 shows the maximum deformation of the sidewall with a wheel load of 7000 N and three rim widths according to the measured data in Figure 4.

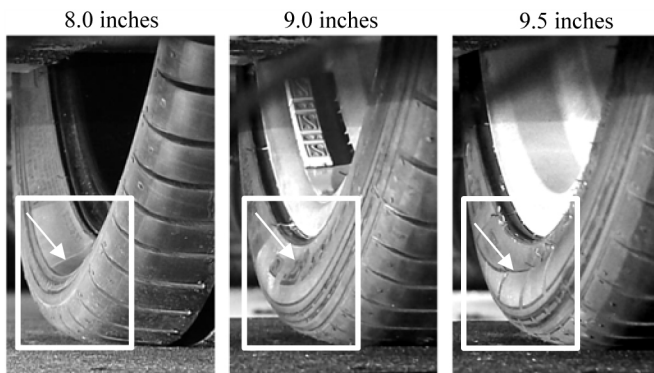


Figure 5. Maximum lateral deformation for different rim widths

As seen in Figure 5, a larger rim width leads to a smaller deformation of the sidewall area, which also causes a higher lateral stiffness. The tyre's sidewall area with the greatest deformation changes for different rim widths. For 8"-tyres the largest deformation is located in the middle of the sidewall area, whereas for 9"- and 9.5"-tyres the largest deformation can be obtained between the tyre mounting area and the rim flange protector.

Figure 6 shows the influence of the rim width on the cornering stiffness for two different tyres with different dimensions. In addition, inserted arrows indicate the effective direction by increasing the rim width.

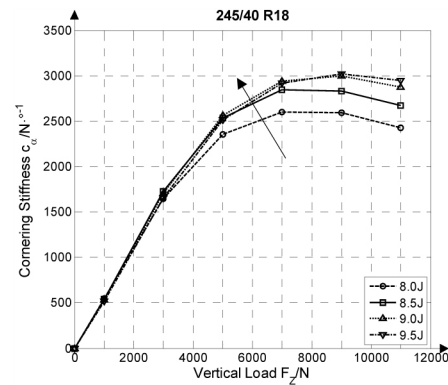
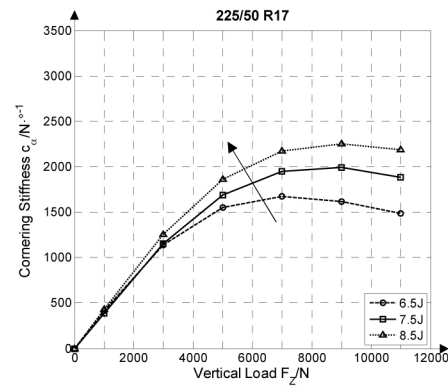


Figure 6. Influence of the rim width on the tyre cornering stiffness for two different tyres

By increasing the rim width, the cornering stiffness increases for middle and high wheel loads. With a wheel load of 9000 N and an increasing of the rim width by 1" the cornering stiffnesses growth is in between 9 and 23 %. The strong increase of the cornering stiffness of tyres with a dimension of 17" is remarkable. A possible explanation can be found by considering the higher height-to-width relation of this tyres. A higher sidewall height leads to a decrease of the lateral stiffness and thus leads to greater differences of the cornering stiffness by an increased rim width. A lower influence of the rim width can be obtained for low wheel loads.

An increasing of the rim width from 9" to 9.5" leads to a saturation of the increasing cornering stiffness (for the investigated tyres with a dimension of 18"). A further enlargement of the rim width does not lead to significant effects. By further increasing of the rim width out of the recommended rim width range of the ETRTO, this explained saturation cannot be shown for tyres with a dimension of 17".

Relaxation Length

The relaxation length describes the dynamic behaviour of a tyre to a sideslip angle step. Figure 7 shows the relaxation length as a function of the wheel load for two tyres and different rim widths. In addition, inserted arrows indicate the effective direction by increasing the rim width.